GEOMORPHOLOGY OF THE KOSCIUSKO BLOCK AND ITS NORTH AND SOUTH EXTENSIONS

W. R. BROWNE

[Read 26th April, 1967]

(Plate III)

Synopsis

A topographical account is given of the high country from Kiandra south to the Victorian border, bounded by the Eucumbene–Snowy and Indi rivers, with particular reference to the portion between Jagungal and Cascade Creek (the Kosciusko block). Lineaments are prevalent, mostly indicating ancient shear-zones, and the evidence suggests that these became the loci of Kainozoic faults. In common with the rest of the eastern highlands the area experienced Tertiary crustal movement, chiefly, it would seem, in the Eocene, late Miocene and later Pliocene, and it is thought that the Kosciusko block was differentially elevated above the adjacent country, probably in at least three stages, during the last of these epochs.

Attention is drawn to the influence on the topography of rock composition and structure and of glacial sculpture, and the characteristics of a number of the principal streams are briefly described.

INTRODUCTION

The following notes are based on incidental observations made over the last 25 years in the course of field-studies, chiefly of the glacial aspects of Kosciusko geology, combined with the examination of contour-maps and air-photographs. They are necessarily very incomplete, and will certainly need revision, but the improbability of opportunities for future field-work has prompted this recording of results in the hope that other geologists may be incited to more detailed examination of the problems considered. Certain of the matters dealt with at some length here have been touched on in previous papers, references to which are made below.

The work of earlier investigators was hampered by lack of reliable maps and by difficulties of access. The latter have been to a considerable extent resolved by roads and tracks made by the Snowy Mountains Hydroelectric Authority; the former drawback was partly made good by the very useful topographic map with spot-heights, made by the State Department of Lands in 1944, but the present study would have been impossible without the accurate topographical maps produced by the S.M.H.E.A. over the past 15 years. I am under great obligation to the Authority for copies of these and for the loan of air-photographs, and to the Commonwealth Bureau of Mineral Resources for making available a set of air-photographs. Free use has been made of the excellent reconnaissance reports and geological maps of parts of the area by members of the Geological Survey of N.S.W., and frequent references are made to them below.

Over the years I have been very fortunate in having the help and companionship in the field of a number of geological colleagues including Mr. W. H. Maze and Dr. J. A. Dulhunty, Drs. T. G. Vallance and G. H. Packham and, more recently, my wife, Dr. Ida A. Browne. Dr. Marie E. Phillips and Messrs. D. Wimbush and D. Svenson have shown me features of geological interest, and Mr. D. G. Moye, until recently Chief Geologist of the S.M.H.E.A.,

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The replication of names of rivers and creeks within the area described may cause some confusion to the reader; there are three Diggers Creeks, two each named respectively Waterfall, Dead Horse, Farm, Sawpit, Cascade and Toolong, and one Boogong and two Bogong Creeks; there are Pound Creek and Pounds Creek, Bull Creek, Bulls Head Creek and Bulls Peaks River, Snowy Creek (tributary to the Indi) and Snowy River, Geehi Creek and Geehi River, Swampy Plain Creek and Swampy Plain River. There are also two peaks named Round Mt. and two eminences called Granite Peak and Granite Peaks respectively. In most instances where any of these is mentioned in this paper the context should make clear which is meant.

Most of the country on the east of the area is referred to as it appears at present, but with the completion of a dam below Jindabyne that village will be submerged together with the Snowy valley up towards Kalkite and Waste Point. Already a new Jindabyne is in being a little distance south of the old, and part of the Kosciusko road from Jindabyne *via* The Creel and Waste Point has been superseded by another skirting the western margin of the area to be submerged. The Eucumbene River is dammed 5½ miles up from Eastbourne bridge, and the country upstream below 3,800 feet submerged.

General Description

(Plate III)

The tract of country here referred to as the Kosciusko block is part of the Southern Highlands of New South Wales near the Victorian border, and includes the highest land in the continent, culminating in Mt. Kosciusko (7,314 ft.). From this point it stretches some 23 miles N to Mt. Jagungal and 9 miles to the south and it extends EW for some 30 or 35 miles between the Eucumbene-Snowy and Indi (Upper Murray) rivers, with a maximum relief of some 6,000 feet in that distance. From the country immediately E and W the block rises so sharply as to suggest that it is of the nature of a horst, for which, however, precise tectonic limits are hard to define. On the east a fairly satisfactory meridional boundary may be drawn south along the Eucumbene River following the Eucumbene fault, then turning SSW along the Waste Point fault marking the western wall of the Snowy valley. For the west of the block one might draw an irregular boundary, altitudinal rather than tectonic, traversing the lowlands of Bridge Creek, Swampy Plain River and the Indi River, but if these are fault-troughs, as is possible, the line would be unsatisfactory. The structural significance, if any, of the Indi is obscure; for most of its length it seems to be merely a deep trench incised in a belt of highland country passing SW from N.S.W. into Victoria, determined in part by ancient faulting, whilst the northerly continuation of its general trend, passing up Tumbarumba and/or Mannus Creek, marks a break between the higher country on the east and the lower on the west. For present purposes the Indi forms a convenient boundary. The fall to the SE is defined by fault-steps and the lineament of Mowamba River may be regarded as bounding the block, but on the north beyond the stated limit the downthrow is less than elsewhere and the horst seems to merge into the general level of the highlands. In the south has generously placed at my disposal his unrivalled knowledge of the geology and topography, has kindly read and discussed these notes in draft manuscript and has in many other ways shown a practical interest in the work. To all these helpers I am most grateful, but for all observations and conclusions the responsibility is mine alone. A number of my interpretations differ from those given by Mr. Moye in a recent brief account of the tectonics of the area (in Cleary, Doyle and Moye, 1964, pp. 101–104).

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In this essay the topography is interpreted as the result of repeated differential uplift of a Miocene peneplain surface along submeridional fault-planes, with concomitant faultings in other directions. Post-uplift erosion, fluvial and glacial, has profoundly modified the *terrain* and obscured many structural details, particularly at the higher levels where Pleistocene glaciers were most active and where rainfall, now of the order of 100 inches *p.a.* and probably much higher in Pleistocene time, has been a powerful agent of erosion.

In these notes it may seem that the concept of faulting as opposed to differential erosion to explain the major features of the topography has been used to excess. In general the facile appeal to faulting is to be deprecated, but the widespread occurrence of ancient belts of weakness has been abundantly demonstrated for the area and there is what is believed to be good evidence that many of these have been the loci of Kainozoic faults. The topography of much of the area is shown in the folding contour-map in an earlier paper (Browne and Vallance, 1957).

Miocene Peneplain

The original suggestion that the Kosciusko block is the result of differential elevation by faulting is due to David, who (1908) postulated step-faulting for its eastern side. Sussmilch (1909) envisaged bounding faults east and west, and further faulting was suggested by Browne *et al.* (1944) and Noakes (1946). The deduction that the original surface was a peneplain is based on the appearance of the topography at various levels when viewed from suitable vantage-points, from which, despite severe river-erosion, the distant skyline is seen to be singularly smooth and level. Looked at from east or west the Summit plateau exhibits this characteristic remarkably well. From the top of Mt. Kosciusko or Mt. Twynam the distant horizon, particularly to the north, shows the same uniformity, though anyone familiar only with the broken country SW of Jagungal might find this hard to believe. Viewed from the east Grey Mare Range has a smooth and level profile merging up into a monadnock, the westerly prospect from which discloses an apparent succession of more or less uniform meridional ridges stretching away towards the Murray River. Ramshead Range, the Thredbo plateau across the Crackenback River, the Burrungubugge ridge, the Brassy Mts. and The Kerries, though at varying altitudes and interrupted here and there by cols and monadnocks, are clearly dissected peneplain remnants, and to the south the Tin Mine plateau is evidently part of a peneplain at a lower level. In the northern extension of the block beyond Jagungal the old peneplain surface is plainly recognizable at many places, linking up with that at Tumut and Batlow. Around Kiandra, Cabramurra township and elsewhere the surface is cut partly in Oligocene basalt overlying valley-deposits of sand, gravel and clay, and in the east the Adaminaby plateau and its southern continuation, from which the Kosciusko block rises, are composed in part of Oligocene basalt and sub-basaltic deposits. It is thus evident that the faulted surface forming the Kosciusko block and its extensions is that of the Miocene peneplain, relics of which are so common in other parts of the eastern highlands.

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Lineaments

(Plate III)

The Kosciusko block and its extensions to north and south abound in lineaments, manifested in the straightness, alignment and parallelism of river-valleys and to a less extent of scarps. Only the more prominent are plotted; many others have been noted by Adamson (1955), Hall and Lloyd (1954), Moye (in Cleary *et al.*, 1964) and den Tex (1959).

Accurate plotting of lineament-trends is, of course, impracticable and the lines shown on the map are at best approximate whilst some are rather conjectural. The negative lineaments marked by relatively youthful valleys are more reliable than the positive, defined by scarps which may have been substantially modified by erosion.

On the east of the area the meridional lineament along the Eucumbene valley is evident nearly to Kalkite Mt., beyond which the much-dissected scarp of the Kosciusko block bears away to the SSW, though the general meridional trend of the river is maintained as far south as old Jindabyne. In the middle of the block are a number of prominent parallel lineaments, the most conspicuous being that made by the straight valley of Guthega River, which is aligned with Upper Windy Creek and a small tributary of Geehi River farther north; on the south the lineament follows up Farm Creek and Upper Betts Creek and may continue south of the Crackenback River. The line of Upper Munyang River is prolonged north over Schlink Pass into Dicky Cooper Creek and Duck Creek, and on the south may follow up Perisher Creek and cross Ramshead Range. The lineament of Valentine River–Finns River, virtually parallel to this, may be continued to the north.

Lower Spencers Creek follows a generally straight course within a meridional belt of intensified foliation which also contains the lower stretch of Wrights Creek. The belt is prolonged north in tributaries of Three Rocks Creek and a tributary of Windy Creek, crossing the latter in the vicinity of Leaning Rock falls; to the south it passes up the valley of Trapyard Creek, through the deep col at its head and across the Crackenback, continuing by collinear tributaries of Mowamba River to Waterfall Creek, a tributary of Jacobs River.

Lady Northcote Canyon is cut along a meridional line to its head at Moraine Pass, and the lineament probably continues south as the eastern scarp of the Etheridge Range, though it may bend slightly west to follow Upper Cootapatamba valley and Upper Leatherbarrel Creek. Diggers Creek, entering the Snowy near Island Bend, makes a lineament that passes south near Pretty Point and may cross the Crackenback. Other lineaments in the eastern half of the block trend approximately SSE, viz. those of Munyang River, Tolbar Creek–Dead Horse Creek and stretches of Gungarlin River collinear with Bundara Creek and Kalkite Creek respectively. The Burrungubugge River lineament may curve to the SE along the Upper Snowy.

In the SE is a series of conspicuous lineaments. From Diggers Creek to Spencers Creek the Summit road follows a remarkably straight course along a number of collinear valleys belonging to the Snowy system, its general direction parallel to that of the Crackenback River. The latter makes with Dead Horse Creek a lineament 25 miles long, the most striking and impressive in the whole region. Parallel to it but much less well defined are the Little Thredbo–Wollondibby lineament and that of Mowamba River. There appears also to be a minor parallel lineament along the Ramshead Range and another following Upper Wrights Creek and Merritts Creek.

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In the SW are the parallel lineaments of Jacobs River and Moyangul River, the former cutting off the Little Thredbo and Mowamba lineaments, and the NS line made by Lookout, Bills Garden and Toolong creeks.

On the west the sinuous lineament of Geehi River may be traced to its head and is prolonged by Straight Creek and the headwater valley of Tumut River, whilst the Bogong Creek lineament continues north through Pretty Plain, along a stretch of the Tooma River and perhaps farther still. In the NW a lineament is made by Upper Welumba Creek trending south and passing some 2 miles E of Khancoban, where it forms the eastern wall of Swampy Plain valley. Other lineaments are noted in the next section.

For the lineaments as a whole no well-defined pattern emerges. Submeridional trends are dominant, varying from about N 10° W on the east to N 10° E on the west; thus the two groups converge northwards at a very acute angle, and those on the west seem to persist farther north. The Crackenback lineaments have a pretty constant azimuth around 240°, and almost at right angles to these are the NW to NNW trends in the east and SW. One might expect some offsetting at fault intersections, but as the hade is probably small this may be neglected.

Hobbs (1911) stressed the significance of topographic lineaments as indicators of direction of jointing and faulting. In the Kosciusko area most of the negative lineaments are closely related to belts of shearing or intensified foliation, as emphasized by Moye and den Tex, or to zones of close jointing, but while it is believed that many of these formed the loci of Kainozoic movements it is clear from the field-evidence that not all of them functioned in this way, since sheared and close-jointed granites have been found on crests of ridges.

The widespread occurrence of zones of shearing in the area is evidence of ancient (probably Palaeozoic) deep-seated relative movement, horizontal and/or vertical, due to horizontal compression, and when the present land-surfaces on either side of a lineament are similar in appearance but at substantially different levels the evidence for Kainozoic faulting is strong and in this study is held to be reasonably conclusive, particularly where rocks of about the same erosional resistance are concerned. The positions of some of the inferred faults were tentatively plotted in a previous paper (Browne, 1952) but further field-examination and study of topographical maps have necessitated much modification. It should be emphasized that the mere occurrence of a lineament does not *ipso facto* imply the existence of a Kainozoic fault, for apart from any differential vertical movement the course of a river-valley may have been determined by an ancient shear-zone; no evidence of Kainozoic faulting, for example, has been observed along the lineaments of Bundara Creek and Kalkite Creek though Hall (1955) found small shears on the bank of the latter creek. On the other hand scarp-lineaments may well betoken faults that did not exist prior to Tertiary time.

Fault-steps, Horsts and Fault-troughs

(Plate III; Figs 1 and 2)

Though generally much modified by erosion, traces of the Miocene peneplain may be discerned on the present surface, and its variation in altitude on adjacent fault-steps affords some measure of the extent of the dislocation. The faulting is illustrated in the profile-sections forming Fig. 1; these show clearly that the major faulting of the block has been marginal and has been markedly greater on the western than on the eastern side.

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Eastern Side

A stepped pattern may be observed in the course of a traverse west from the Eucumbene River. At the Eastbourne bridge the river (3,390 ft.) is some 500 feet below the Adaminaby plateau and is bordered by what appears to be a dissected river-terrace less than ½ mile wide at about 3,600 feet. This is backed by the remnant of another surface at 4,200 feet and behind it is the Nimmo platform, rising to nearly 4,900 feet, which persists to north and south, attaining 5,000 feet in a few places to the south, and rising to much higher levels in the north. Out of this the Gungarlin River has carved a wide, mature and locally swampy valley known as Snowy Plains. Behind it is Burrungubugge ridge, the dissected remnant of a fault-step with a summit level between 5,600 and 5,800 feet, interrupted by two wide and conspicuous cols, Brassy Gap (5,360 ft.) and another a mile south at 5,440 feet. This step is cut obliquely by the Burrungubugge River, and behind it the Brassy Mts. step containing the Main Divide rises to more than 6,200 feet, fronted by a submeridional scarp. As noted in an earlier paper (Browne *et al.*, 1944), there appears to be a flight of small steps between the Brassy Mts. and Burrungubugge River; some of these may be erosional but the Tolbar Creek–Dead Horse Creek lineament is certainly suggestive of a minor fault throwing ENE. The actual positions and directions of the postulated faults bounding Brassy Mts. step and Burrungubugge ridge step are uncertain, though the step-structure is clearly marked. Perhaps the former fault should be shown a little more to the east and cut off northwards by an extension of the Burrungubugge fault to Doubtful River, and the latter rotated so as to be collinear with the Brooks Mill fault.

The Brassy Mts. step slopes gently west to the wide, swampy valley of Valentine River, beyond which is the flattish ridge of The Kerries at 6,700 feet, dying out to the south in Disappointment Spur and apparently merging northwards into the Brassy Mts. level. The ridge gives the impression of a horst bounded east by Valentine River and Finns River and west by Duck Creek, Dicky Cooper Creek and Munyang River. It culminates in the low monadnock of Gungartan.

If now the traverse is continued to the SW across Munyang River the Granite Peak ridge is first reached, rising to 6,500 feet and extending north to Dicky Cooper Bogong. Mr. Svenson suggested that there are a number of small meridional step-faults on either side of the Granite Peak horst, throwing down to the east on the Munyang side and the west on the Guthega side. This may well be, and indeed the wide basin of Munyang River may conceivably mark the site of a fault-trough tapering to the north. The next step, west of the Guthega lineament, has a general level below 6,400 feet in the north suggesting a shallow tectonic depression, though the discrepancy seems to diminish south of Consett Stephen Pass. Across the Spencer Creek lineament the Miocene peneplain surface probably attains an altitude of 6,800 feet or more, but a reliable estimate is difficult. West of it the Lady Northcote fault has no marked topographic expression, but there is certainly rather more ground over 7,000 feet to the west than to the east of it. The narrow Summit horst has but a small visible extent, having suffered severely from post-uplift erosion.

A traverse across the country SE of the Upper Snowy discloses some differences in the fault sequence. The Summit road ascending from the old Crackenback River bridge at The Creel passes over level stretches at Waste Point (3,100 ft.) and Sawpit Creek (4,100 ft.). The first is probably an erosional river-terrace similar to that noted at Eastbourne bridge; the other may be equivalent to the 4,200-foot step at Eastbourne bounded east by the

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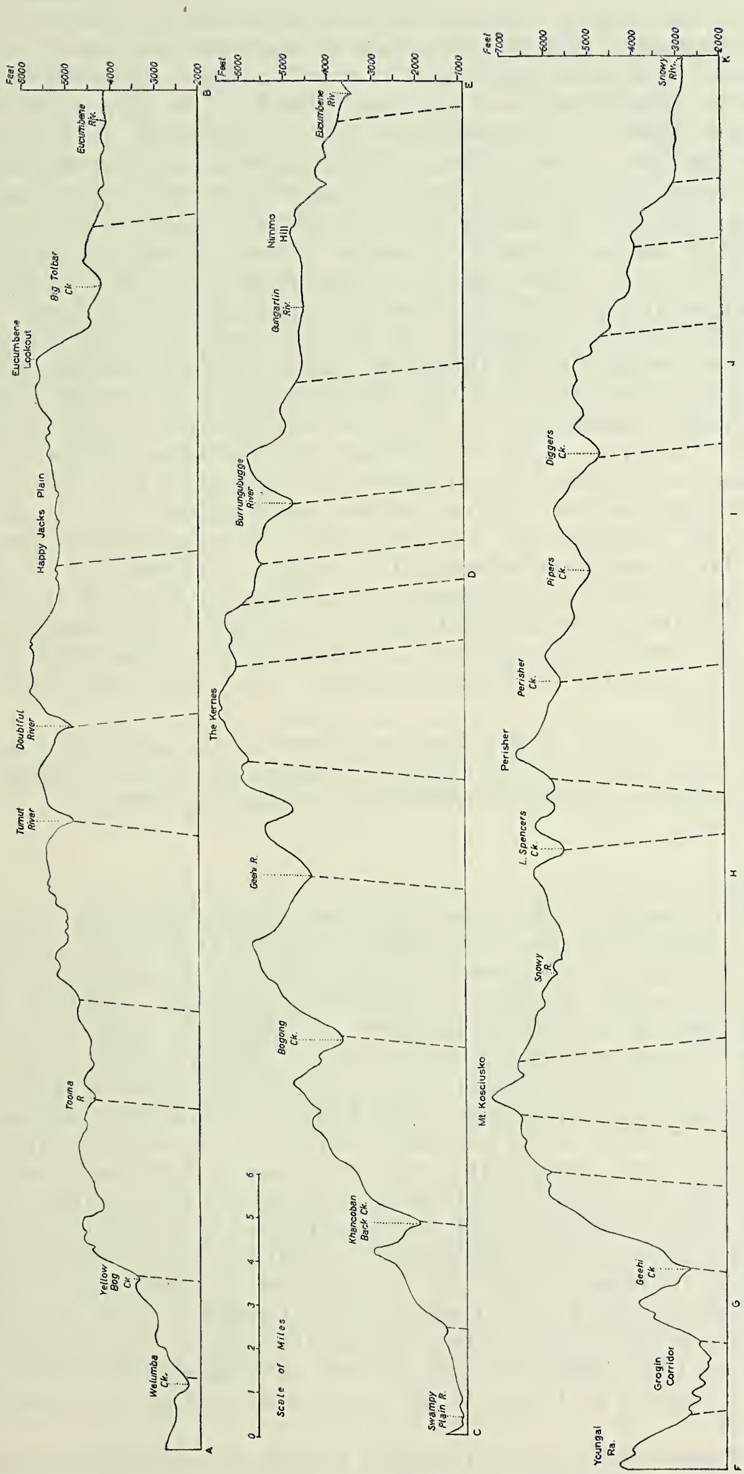
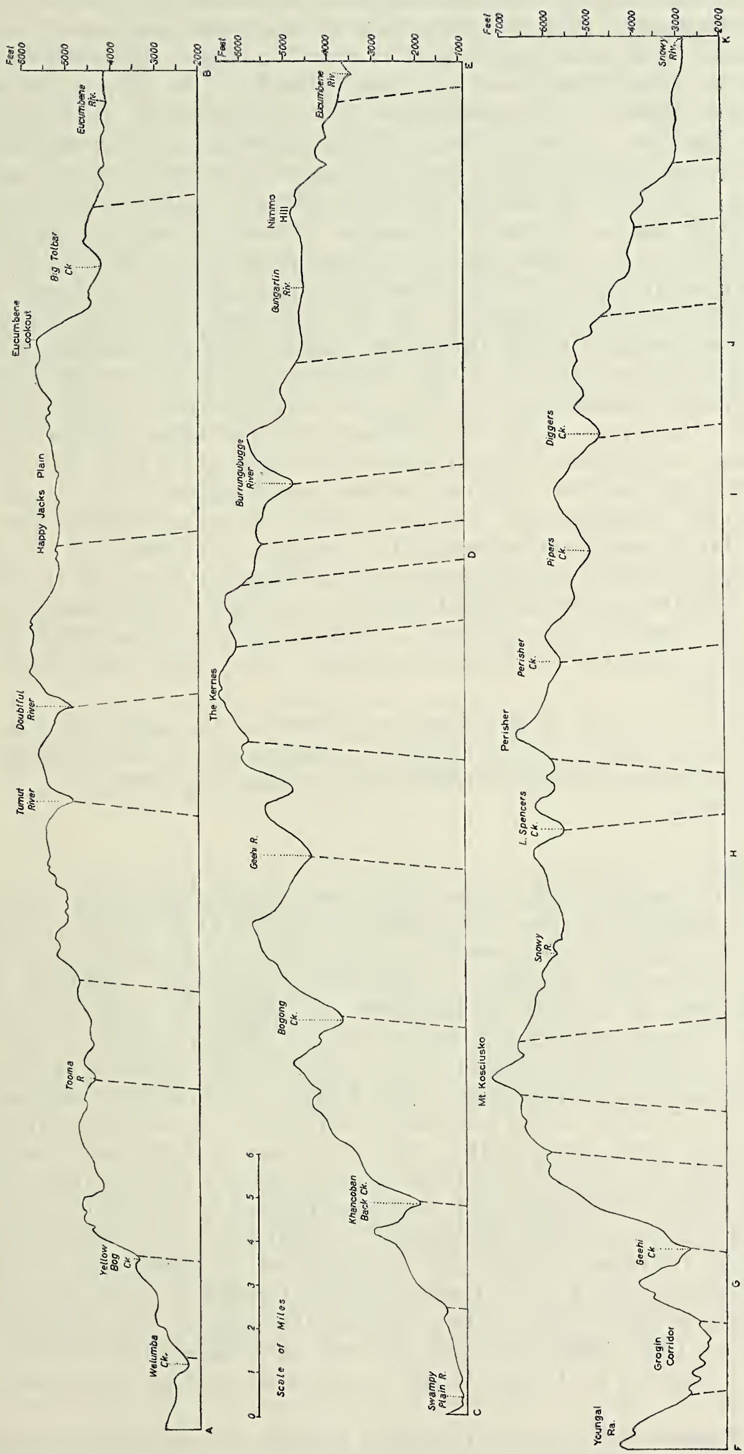


Text-fig. 1. Profile-sections across the Map (Plate III).



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Waste Point fault and west by a parallel fault cutting the Summit road at the Sawpit Creek crossing. West of this is a step reaching 4,800 feet, bounded west by the lineament following Brooks Mill Creek and apparently equivalent to the Nimmo level, and higher still is the Panorama ridge step, traversed by the road at Rennix Gap and reaching 5,600 feet. In between there seems to be a step at 5,300 feet, bounded west by a NS lineament running just east of Andrews Lookout, in which Boggy Plain (5,180 ft.) is excavated.

David (1908) suggested that Diggers Creek follows the line of a meridional fault passing just east of Pretty Point (5,920 ft.), where it has an easterly throw of about 250 feet. This fault seems to have no continuation north of the Snowy, and on the other hand the prominent Brassy Mts. step does not persist south of the Snowy. The Kerries ridge likewise disappears between Gungartan and the Snowy River, and the next sign of crustal movement is marked by the Perisher Creek lineament, beyond which is the much-dissected Perisher Range culminating in The Perisher (6,743 ft.)* and contrasting with the country immediately to the east, which barely reaches 6,000 feet, and with The Paralyzer (6,523 ft.) on the west. The same dominance appears farther south in Ramshead Range, where Mt. Wheatley and The Porcupine exceed 6,300 feet, and the strip as a whole would appear to be of the nature of a horst. The Guthega and Spencers Creek lineaments cross the Snowy, Ramshead Range and Crackenback River, with a continuance between them of the trough-structure noted north of the Snowy. West of the Spencers Creek line heights exceeding 6,700 feet are attained in the Kangaroo ridge, and across the Lady Northcote fault in Ramshead Range the general altitude is higher still, reaching 7,000 feet in places. The same rule holds in the Thredbo plateau.

The failure of some of the steps to persist to the south may be due to meridional faults being cut off against a Snowy fault, the wedging out of steps or local horsts between undetected intersecting faults, or the dying out of the faults.

Western Side

From the summit of Mt. Kosciusko the surface falls away very steeply to the west, dropping more than 5,800 feet to the Indi River in a distance of 8 miles. Owing to heavy dissection recognition of fault-steps is well-nigh impossible. The ridge forming Mt. Kosciusko descends abruptly, possibly through faulting, to a shelf or platform at 6,600 feet, traces of which are also visible a few miles to the north and south. There appears to be another step at about 6,000 feet, fronted by a steep slope leading down to the conspicuous Geehi Creek lineament some 4 miles west of Mt. Kosciusko. This is traceable for 5 miles, being prolonged southward to the headwater stretch of Snowy Creek. The ridge to the west of it rises to 4,850 feet, and there is little doubt that the lineament marks a fault throwing more than 1,000 feet and that the ridge, its flanks east and west fretted and nibbled by countless small torrents, is the eroded remnant of a fault-step. It in turn falls away rather steeply to form a wall that flattens out at 2,500 feet to the wide Grogin corridor running from Geehi to Tom Grogin and crossing the Indi obliquely into Victoria; this is bounded on the west by the Youngal Range rising to more than 4,800 feet, and may be, as suggested by Moye, a fault-trough. It is drained by Bridge Creek to the north and by an unnamed creek to the south.

None of these lineaments is traceable farther north than the Geehi River, but it is highly probable that, as suggested by Moye (in Cleary *et al.*, 1964,

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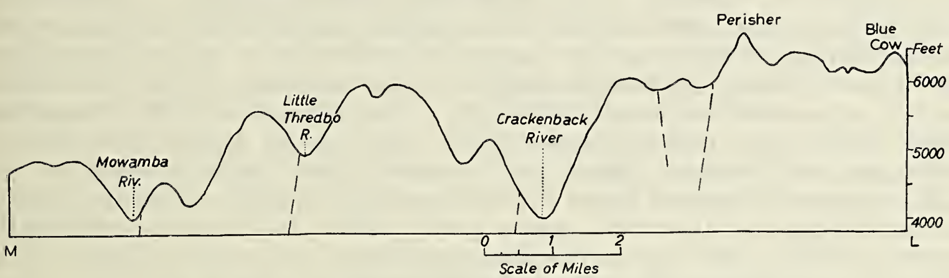


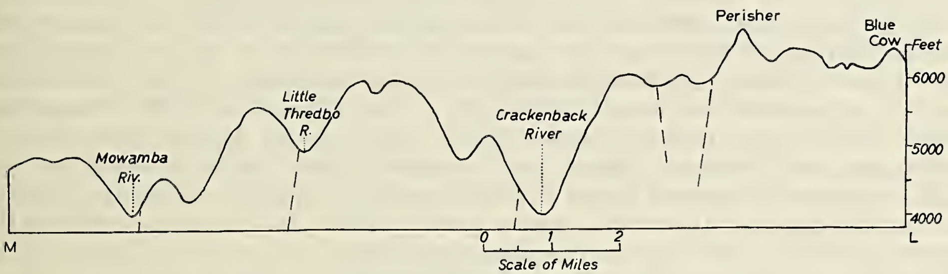
Text-fig. 2. Profile-section SSE through The Perisher.

South-East

The country descends by a series of great fault-steps bounded by parallel rivers of the Snowy system (Fig. 2). The most important and the most conspicuous fault in the whole area follows the Crackenback valley, first recognized as marking a fault by David (1908). On its left bank Ramshead Range varies from 6,600 feet in the SW to 5,900 in the NE and the Thredbo step or plateau on the right bank from 6,200 to 4,600 feet. This is bounded in turn by the fault making the Little Thredbo-Wollindibby lineament. The next ridge, between the Wollindibby and Mowamba faults, varies from 6,000 to less than 4,000 feet and the country SE of it is lower by more than 400 feet.

The decline of the steps in altitude from SW to NE is doubtless in part an erosional effect, but cross-faulting is also responsible; the Thredbo step, for instance, is crossed by submeridional faults and in one place is breached by the very striking lower valley of Little Thredbo River, which divides it into a higher western part and an eastern part lower by more than 1,000 feet. A road-cutting near the river displays fairly close-spaced vertical jointing in the granite with a strike of *ca.* 165° (true), perhaps related to an adjacent fault.

On the SW the Crackenback fault continues along Dead Horse Creek almost to the Indi River, but the Wollindibby and Mowamba faults seem to be cut off by a fault along the Jacobs River lineament. On the NE all the faults would appear to terminate against the Waste Point fault, as there is no topographic indication of any of them beyond it. If this is correct the map), they swing round to the NNE in general conformity with the belts of metasedimentary rock enclosed in the granite. Certainly the great topographic blocks of Grey Mare Range and The Dargals seem to be separated from each other and from the higher country on the east by faults along Geehi River and Bogong Creek, as pointed out by Hall and Lloyd (1954), some of which may diminish in throw and die out northwards. The highest plateau surface at 6,200 feet is followed west by Grey Mare Range, a ridge or step, flat-topped in places, varying from a little over 5,000 feet in the south to about 5,400 feet in the Toolong Range. Separated from it by Bogong Creek is The Dargals Range, a long, narrow remnant rising north from 5,000 to a little over 5,200 feet. West of this the country is very deeply dissected by tributaries of the Indi, but some of the rapid descents, like that at Yellow Bog Creek, are probably due to faulting and the Welumba Creek lineament almost certainly marks a fault with heavy westward throw that may continue south as the eastern wall of Swampy Plain valley. Whether this wide valley-plain at 2,000 feet is a fault-trough is not known; it is separated from the Indi River by the Indi Range, rising to 3,000 feet.



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The Summit Road lineament is thought to mark the course of a fault hading SE; in the NE it may end against the Diggers Creek fault.

Between the Crackenback River and the Summit road is a minor parallel lineament indicated by close jointing along a branch of Wragges Creek, and by alignment or parallelism of the valleys of Wheatley and Rock Creeks and a tributary of Diggers Creek. The surface on the SE is as much as 100 feet higher than that on the NW, which may form the eroded floor of a shallow fault-trough.

It has been suggested that the Upper Snowy valley follows the course of a fault. True, the country is on the whole higher on the left than on the right bank, and between Island Bend and Guthega River the valley is closely parallel to that of the Crackenback, but upstream the parallelism disappears, and the fault, if there is one, may die out or be cut off.

Northern Extension

Beyond the latitude of Jagungal much of the surface on the east is considerably over 5,000 feet, but is extensively dissected by the headwaters of the Gungarlin River and by Happy Jacks River and other tributaries of the Tumut. Along the eastern margin extensive erosion by the Eucumbene and its tributaries has made it difficult to trace the course of the Eucumbene fault, which may follow Hughes Creek and Nungar Creek. The Summit peneplain level between Tumut and Doubtful River faults, about 6,100 feet A.S.L. south of Jagungal, drops rather abruptly to 5,600 feet, perhaps through cross-faulting, but thereafter slopes gently NNE. To the east and NE the surface reaches 5,600 feet in the Munyang Range and north of Happy Jacks Plain, but slopes away thereafter so that it does not exceed 5,000 feet beyond Kiandra on the north and Tumut River on the west. Transverse profile-sections (Fig. 1) emphasize the westerly slope of the surface and the rapid descent of its western margin through step-faulting. There are faults also along and/or near the Tumut River, but whether any exist between it and the Eucumbene fault is not known, though submeridional shatter-zones were encountered in the Eucumbene–Tumut tunnel near Eucumbene Lookout.

It is of interest that in the latitude of Kiandra there appears to be no great disparity in elevation between the Kosciusko plateau sloping north and the country to the east where the elongated high land-mass of the Australian Capital Territory is descending to the south. These two highland masses, both submeridional in trend and both notably elevated above the level of the adjacent Southern Highlands, are arranged *en échelon.*

Southern Extension

South of South Ramshead the surface drops abruptly to Dead Horse (Grogin) Gap, through which the Crackenback fault passes; on the ridge beyond the peneplain surface barely reaches 6,000 feet and south of Cascade Creek it does not rise above 5,500 feet, possibly as the result of cross-faulting. A few miles north of Tin Mine Huts it has fallen to 4,600 feet and is traversed by shallow, swampy, meandering valleys, some tributary to the Indi, others to the Snowy. In this surface the Indi is entrenched to more than 2,000 and the Snowy to more than 3,000 feet, and the valleys of Jacobs, Moyangul and Ingeegoodbee rivers and their tributaries deepen rapidly to profound gorges, breaking up the plateau into ridges. Tin Mine plateau may have been let down by the Moyangul River fault against the country to the NE, which rises to more than 5,400 feet. This latter wedge of country, cut off to the east by Bills Garden fault, is succeeded by the Charcoal Range step (4,800 ft.), recent Berridale earth-tremors in the country to the NE (Cleary *et al.*, 1964) may not have been directly related to the Crackenback fault.

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Monadnocks

Above the Miocene peneplain surface at its various altitudes rise several erosion-residuals. One of the most familiar to those visiting the Summit is Jagungal (6,764 ft.) on the northern horizon; others are Mt. Tate (6,789 ft), the shapely Dicky Cooper Bogong (6,570 ft.), Gungartan (6,788 ft) and Big Brassy (6,450 ft.). Viewed from Grey Mare Range a strip of country 10 miles long by 2½ miles wide, extending from a little N of Mt. Twynam (7,207 ft.) south to South Ramshead (7,189 ft.), and rising above the peneplain surface, has the appearance of a residual mass, the more conspicuous from the complete absence of trees. In addition to the high points mentioned it includes Mt. Kosciusko, Mt. Townsend (7,251 ft.) and North Ramshead (7,145 ft.). The Grey Mare Range is crowned by a narrow monadnock ridge with a few peaks, culminating in The Grey Mare (6,139 ft.). The residuals of the Thredbo plateau include Drift Hill (6,340 ft.) and Paddy Rushs Bogong (6,300 ft.) and on the southern extension the most striking monadnock is The Pilot (6,005 ft) towering 1,400 feet above the general surface of Tin Mine plateau. In the east Kalkite Mt. (5,101 ft.) is a conspicuous landmark.

All the residuals north of the latitude of Jagungal are well below 6,000 feet, the principal being Cabramurra or Tabletop Mt. (5,858 ft.), the graceful cone of Round Mt. (5,762 ft.), The Bald Hill (5,787 ft.) and Tantangara Mt. (5,702 ft.).

The Main Divide

The watershed between the Snowy and Murray systems, which is part of the Main Divide of eastern Australia, has a general NNE trend following the backbone of the country from The Pilot to beyond Kiandra, with a big embayment to the east beyond Jagungal to take in the drainage of Happy Jacks River. Locally it runs NS at Granite Peak and EW at the head of Munyang River. It includes many high points such as Mt. Kosciusko, Ramshead, Twynam and Mt. Tate, but leaves Mt. Townsend, The Kerries and Jagungal on the west, and its elevation varies from 7,314 feet on Mt. Kosciusko to 4,300 feet in the neighbourhood of Tin Mine Huts. In places it is a narrow ridge, as on Muellers Peak, west of Mawson and Club cirques, and at The Pilot; elsewhere, as in the Tin Mine Plateau, it is flat and ill-defined. Six miles N of Kiandra at the head of the Eucumbene it turns sharply to run SE.

Rivers

(Plate III)

General

The Snowy drainage is dominant in the south and that of the Indi in the north of the block. In the northern extension the Tumut River drains an ever-increasing proportion of the country.

The block and its extensions are traversed at various levels by wide, shallow and swampy valleys. These are thought to be earlier Pliocene, but those at the highest altitudes owe their present aspect in some measure to the passage of Pleistocene glaciers, and indeed glacial modification of the landscape at these levels may help to account for the more mature appearance of the higher country observed from the air by Moye (in Cleary *et al.*, 1964).

which in turn descends by the Jacobs River fault to an extensively dissected block rarely exceeding 4,400 feet. This may also be faulted down along the Thatchers Hole—Grosses Plain lineament from the high country to the NW rising to well over 5,000 feet.

Monadnocks

Above the Miocene peneplain surface at its various altitudes rise several erosion-residuals. One of the most familiar to those visiting the Summit is Jagungal (6,764 ft.) on the northern horizon; others are Mt. Tate (6,789 ft), the shapely Dicky Cooper Bogong (6,570 ft.), Gungartan (6,788 ft) and Big Brassy (6,450 ft.). Viewed from Grey Mare Range a strip of country 10 miles long by 2½ miles wide, extending from a little N of Mt. Twynam (7,207 ft.) south to South Ramshead (7,189 ft.), and rising above the peneplain surface, has the appearance of a residual mass, the more conspicuous from the complete absence of trees. In addition to the high points mentioned it includes Mt. Kosciusko, Mt. Townsend (7,251 ft.) and North Ramshead (7,145 ft.). The Grey Mare Range is crowned by a narrow monadnock ridge with a few peaks, culminating in The Grey Mare (6,139 ft.). The residuals of the Thredbo plateau include Drift Hill (6,340 ft.) and Paddy Rushs Bogong (6,300 ft.) and on the southern extension the most striking monadnock is The Pilot (6,005 ft) towering 1,400 feet above the general surface of Tin Mine plateau. In the east Kalkite Mt. (5,101 ft.) is a conspicuous landmark.

All the residuals north of the latitude of Jagungal are well below 6,000 feet, the principal being Cabramurra or Tabletop Mt. (5,858 ft.), the graceful cone of Round Mt. (5,762 ft.), The Bald Hill (5,787 ft.) and Tantangara Mt. (5,702 ft.).

The Main Divide

The watershed between the Snowy and Murray systems, which is part of the Main Divide of eastern Australia, has a general NNE trend following the backbone of the country from The Pilot to beyond Kiandra, with a big embayment to the east beyond Jagungal to take in the drainage of Happy Jacks River. Locally it runs NS at Granite Peak and EW at the head of Munyang River. It includes many high points such as Mt. Kosciusko, Ramshead, Twynam and Mt. Tate, but leaves Mt. Townsend, The Kerries and Jagungal on the west, and its elevation varies from 7,314 feet on Mt. Kosciusko to 4,300 feet in the neighbourhood of Tin Mine Huts. In places it is a narrow ridge, as on Muellers Peak, west of Mawson and Club cirques, and at The Pilot; elsewhere, as in the Tin Mine Plateau, it is flat and ill-defined. Six miles N of Kiandra at the head of the Eucumbene it turns sharply to run SE.

Rivers

(Plate III)

General

The Snowy drainage is dominant in the south and that of the Indi in the north of the block. In the northern extension the Tumut River drains an ever-increasing proportion of the country.

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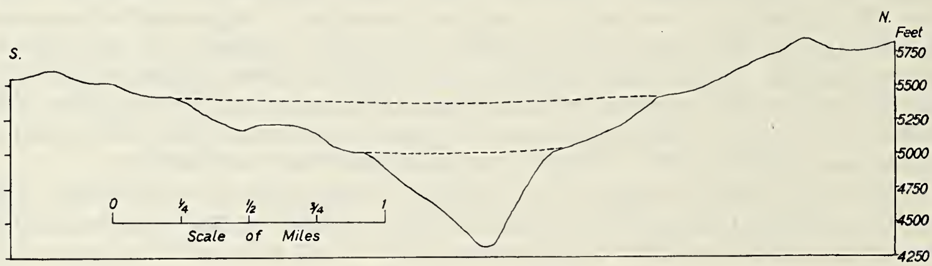
The significance of the distribution of these wide valleys is referred to below; they include the headwaters of the Tooma, Geehi and Tumut rivers, the Gungarlin, the Snowy headwaters and in the north the wide, dissected Happy Jacks Plain. Similar but smaller valleys are a feature of the Thredbo plateau and the Ramshead Range, and at lower levels are the broad, alluviated valley of Wollindibby Creek and the headwaters of the streams on Tin Mine plateau.

Valley-in-valley structure, a sensitive indicator of vertical crustal movement, is common. Remnants of wide, shallow valleys antedating the existing gorges appear along the Upper Snowy (Fig. 3) and Crackenback and, less obviously, along the Eucumbene, the Indi and some of its tributaries; and there are minor valleys incised within some of the main gorges. Excavation by glaciers has given a catenary cross-profile to many of the river-cut valleys at the higher altitudes, with widening and probable over-deepening in places. In progressing up the valley of a trunk-stream rejuvenation has affected the tributaries in turn, so that the lower have been subjected



Text-fig. 3. Profile-section across the Snowy River at the mouth of Munyang River in a general NS direction, showing remnants of the earlier and later Pliocene valleys and the present inner gorge.

to it longer than those farther upstream. Begun, it is thought, in the later Pliocene Kosciusko epoch, the process has continued through Pleistocene time to the present day, though with some intermission while the valleys were protected by ice, and as a consequence quite a number of glaciated valleys show clear signs of rejuvenation, including those of Diggers Creek, Dicky Cooper, Windy, Dead Horse, Lower Pipers and Cascade creeks. As the result of rejuvenation of Leatherbarrel Creek its capture of the headwaters of Cootapatamba Creek is imminent (Browne *et al.,* 1955). Many tributaries, unable to keep pace with the main stream in eroding their beds, join it with steepening gradients and exhibit inflexions or kink-points. This feature is particularly well shown by tributaries of the Upper Snowy, some of whose thalwegs are marked by two inflexions, corresponding probably to successive elevations indicated by valley-in-valley structure in the main stream. Of course, in any tributary the rate of erosion is a function of the volume of water it carries and the existence of readily or difficultly erodible rocks in its bed, and at the higher altitudes a disturbing factor has been introduced by the Pleistocene valley-glaciation.

A number of late-mature or senile E- or W-flowing streams on the higher surfaces become youthful downstream and descend rather steeply to a lower platform where they regain maturity. For instance, Bulls Peaks River rises above 6,000 feet at the northern end of the Brassy Mts., and descends through 800 feet in a mile to Snowy Plains, over which it meanders to join the Gungarlin. Other transverse streams that deepen downstream from a mature or senile condition are Rocky Plain River, Macdonalds Creek, Valentine River, Windy Creek and Dicky Cooper Creek. These peculiarities are

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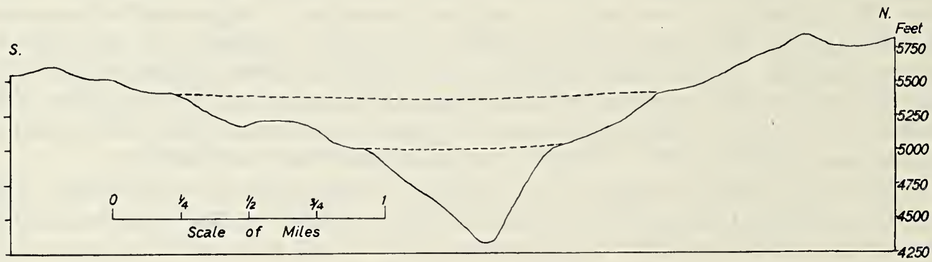

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Quite striking is the prevalence of boathook-bends (Taylor, 1910, 1914) or barbed junctions, where a tributary makes with the main stream an acute angle downstream. Fryingpan Creek (now part of the Eucumbene reservoir), an important and mature left-bank tributary of the south-flowing Eucumbene on the Adaminaby plateau, is directed to the NW and Braemar Creek flows due N. On the right bank S of Kiandra a number of small tributaries also flow north. Farther south the Upper Snowy and Crackenback Rivers and Wollindibby Creek enter from the SW. Guthega, Munyang and Finns rivers and Tolbar Creek make boathook-bends with the Upper Snowy and on the west Geehi River and Bogong Creek meet Swampy Plain River and Snowy Creek joins the Indi River with boathook junctions. A similar relation exists between the Upper Geehi and its tributaries Dicky Cooper Creek and Valentine River, and in the southern extension Jacobs River and Moyangul River have boathook tributaries. This anomalous behaviour is no doubt due in large measure to the oblique intersection of structural or other features controlling the stream directions. River-capture, however, must be invoked to account for the direction of flow of Fryingpan Creek and some smaller left-bank tributaries of the Eucumbene. More than 20 years ago I noted basalt within the wide valley of Buckenderra Creek, an affluent of Fryingpan Creek, at 3,700 feet A.S.L., 300 feet or more below the surface of the Adaminaby plateau, and some years later this outcrop and others, together with underlying drift, were mapped by the Geological Survey of N.S.W. (Adamson, 1955). This valley, therefore (and inferentially that of Fryingpan Creek) existed in Oligocene time. Andrews (1901) showed that at Kiandra the dissected basalt-capped lead adjacent to the Eucumbene slopes to the N and crosses the Main Divide at Bullock Hill, 6 miles beyond the township, suggesting that a north-flowing stream was captured through headward erosion by a south-flowing Eucumbene.

The watershed between the Upper Snowy and Crackenback rivers is very asymmetrical, being much closer to the latter; this peculiarity is apparently related to faulting and the consequent general tilting of the Ramshead Range step to the NW. The surface of the range near the divide is characterized by swampy flats, as at the head of Trapyard Creek and Betts Creek, and in Prussian Flat and Thompsons Plain; these may be relics of the early Pliocene drainage captured from the Crackenback by tributaries of the Snowy. The headwater of Prussian Creek, a tributary of Upper Pipers Creek, is in such a flat valley sloping to the SE, and gives the impression of having been captured at the very edge of the Crackenback valley by the present north-flowing creek.

Tilting of the Thredbo fault-step would explain the marked asymmetry of the Crackenback–Little Thredbo divide, and there is an obvious westerly slope of the Brassy Mts. step towards the Valentine River fault.

Notes on Individual Systems

Eucumbene.—At its head, just N of Kiandra, this river occupies a wide mature valley-plain, and downstream deep gorges alternate with flood-plain tracts as far as Alpine Creek, below which the river leaves the northern extension of the Kosciusko block. Lower down youthful give way to more mature characters, and near the site of old Adaminaby the river was joined by the wide, alluviated Fryingpan and Buckenderra Creeks. At the dam it is already becoming entrenched below the Adaminaby plateau. After receiving the Upper Snowy and Crackenback rivers, which are probably to doubtless due to differential uplift or step-faulting athwart the courses of the streams.

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As Andrews (1910, p. 445) pointed out, the Eucumbene is the structural continuation of what is known as the Snowy, and is really the main stream, though usually regarded as a Snowy tributary. Just above their junction the rate of fall of the Eucumbene is 14 feet and that of the Snowy 20 feet to the mile. In the 5 miles from the junction to old Jindabyne the fall is 25 feet.

Except for Fryingpan and Buckenderra creeks the Eucumbene has no important tributaries. Rocky Plains Creek meanders for 8 miles over the Adaminaby plateau before deepening in the last mile to meet the main stream. Kalkite Creek, only 4 miles long, is notable for rising in a low gap or col at 4,500 feet that leads on to Snowy Plains, and drops about 1,200 feet in three miles.

Evidence of rejuvenation following on uplift is provided by the 3,600-foot terrace at Eastbourne bridge (3,390 ft.), which may be traced at intervals downstream, and by the Waste Point step at 3,100 feet on the Upper Snowy. A corresponding level is visible on the eastern bank of the Snowy valley as a dissected terrace a few miles up from old Jindabyne. Slight rejuvenation is also to be seen in the headwaters just north of Kiandra.

Upper Snowy.—Rising at 6,800 feet on the rim of a shallow basin fronting the Etheridge Range, this river is joined by Merritts Creek from the right and by Rawson Creek heading at Rawson Pass (6,960 ft.). From Charlottes Pass it descends at an average rate of *ca.* 105 feet to the mile for 26 miles to its exit from the Kosciusko block. A few miles below Island Bend it turns sharply right and flows SE to its junction with the Crackenback, and the combined stream joins the Eucumbene 1½ miles further down.

The valley-in-valley structure of the Upper Snowy is of considerable interest. In Fig. 4 is shown as a broken line the thalweg of the older Pliocene outer valley, which appears on the ground as terrace-remnants; it may have been up to 2 miles wide and at least 500 feet deep. The points determined on it by inspection of large-scale contour-maps are really too far apart to be joined by continuous lines, but are linked for convenience. At Charlottes Pass the terrace is at 6,050 feet and 14 miles down near Island Bend at 5,200 feet A.S.L. It may be significant that the thalweg as plotted is apparently continuous with that of the present Snowy above Rawson Creek.

The middle profile represents a valley-level within the main gorge which merges upstream into that of the present river at Charlottes Pass, and may be followed at intervals downstream as a terrace to the vicinity of Guthega River; below this it appears less distinctly as terrace-remnants almost to Gungarlin River. Its incision to as much as 750 feet below the floor of the outer valley affords some measure of the local vertical extent of the first stage in the late Pliocene uplift; however, there is reason to believe that the Snowy glacier, which may have been upwards of 400 feet thick just below Charlottes Pass, caused some widening and perhaps over-deepening of the valley there (Browne and Vallance, 1957), and for some miles downstream. The degree of maturity attained by this valley before later uplift was due in part to the existence of a temporary base-level along the eastern base of the uplifted block.

The lowest profile, that of the present stream, shows a marked inflexion just above the entry of Rawson Creek and a smaller one above Club Lake Creek. Above Charlottes Pass it is only a little below the thalweg of the be regarded as over-developed subsequent tributaries, the valley widens rapidly and at old Jindabyne its floor is nearly 1,000 feet below the plateau on the east.

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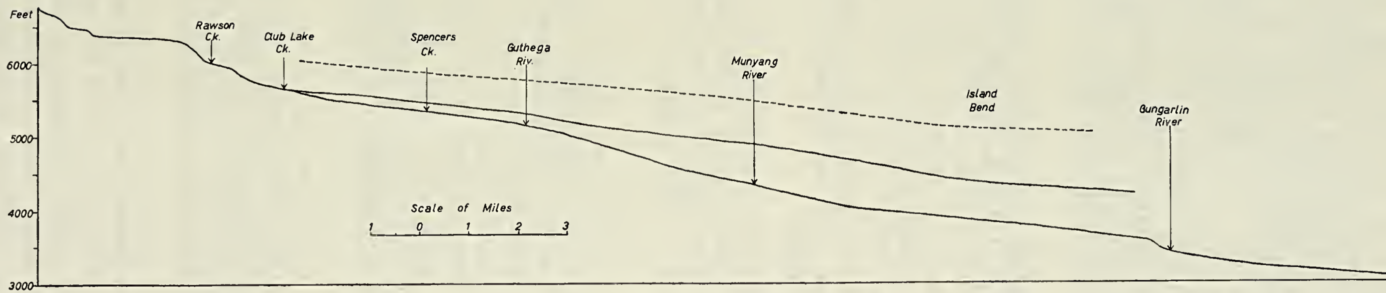
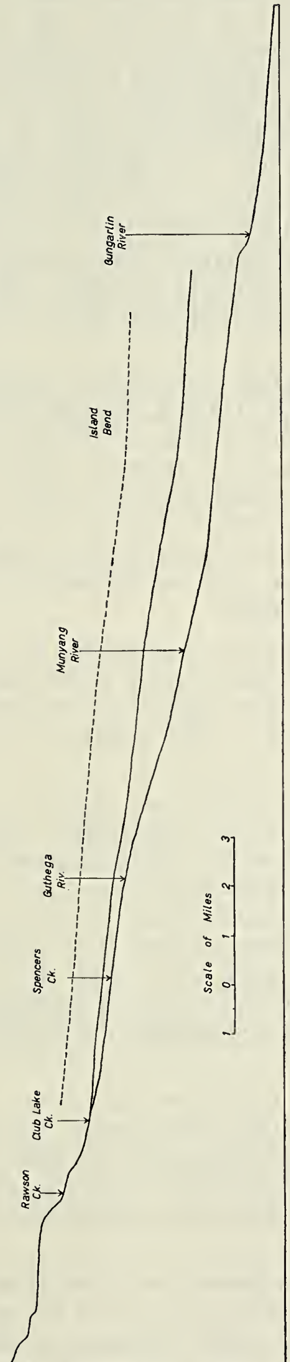


Text-fig. 4. Longitudinal profile of the Snowy River from its head to a point $3\frac{1}{4}$ miles above its junction with the Crackenback. The thalwegs of the earlier and later Pliocene valleys are shown approximately.



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Snowy glacier but downstream diverges from the middle profile, and is 120 feet below it at Guthega River. From this point there is a distinct steepening, and the drop of 800 feet in the next $4\frac{1}{2}$ miles was a determining factor in the siting of the hydroelectric power-station at the mouth of Munyang River. The next steepening (200 feet in a mile) is 3 miles below Island Bend, and thereafter the gradient flattens considerably. No appreciable change marks the exit of the river from the Kosciusko block or its junction with the Crackenback. The inflexions in the thalweg are considered to indicate the upper limits of rejuvenation following on the Kosciusko uplifts, but the two abrupt ones near the head may be related to the Pleistocene glaciation.

The incision of the present stream in the thalweg of the former Snowy glacier below Charlottes Pass strongly suggests that fluvial rejuvenation, interrupted while the valley was protected by ice, was resumed following deglaciation.

The Snowy tributaries exhibit considerable diversity of character. Of those on the left bank Rawson, Club Lake and Blue Lake creeks drain the highest country in the block. Pounds Creek, with an overdeveloped submeridional tributary, also receives drainage chiefly from the high, steep country on the west. The main creek, some $3\frac{1}{2}$ miles long, heads in Twynam cirque and descends more than 1,750 feet to its mouth, with a distinct inflexion 2 miles up at 5,900 feet and a marked flattening of the thalweg to meet the Snowy at 5,250 feet. One of its tributaries drains a cirque on the southern slope of Mt. Anderson.

Guthega River, 3 miles long, is remarkable for its straightness, steep descent of more than 1,100 feet with only a slight inflexion, and absence of significant tributaries. The valley has been determined by a relatively narrow, easily eroded shear-zone in the granite, so that rejuvenation has been comparatively rapid.

Munyang River has several tributaries, mostly on the right bank, and a much larger catchment-area than its neighbours. Near its head a relatively rapid rise of 500 feet, in part due to a thick transverse moraine, leads up to a gently-sloping, swampy, erratic-strewn floor, and the valley-head widens out, especially on the west, through glacial erosion to a great bowl-shaped hollow upwards of 800 feet deep. Down the valley occasional terrace-remnants and isolated hills mark the level of a former valley-floor. Rejuvenation has left a number of tributaries hanging well above the floor of the main valley. Munyang and Guthega rivers both meet the Snowy at grade.

Finns River is hung above the Snowy and from a swampy flat at 4,950 feet drops 950 feet in the last mile of its course. Behind the flat the valley-floor rises more steeply to a very gentle slope at 5,500 feet marking the floor of a cirque, before its final sharp rise to the col (6,200 ft.) at its head. The neighbouring Tolbar Creek descends through 950 feet in $1\frac{1}{2}$ miles to the Snowy.

The largest of the Snowy tributaries is the Gungarlin which with its tributary the Burrungubugge drains an area of 90 square miles. Rising at 5,400 feet it pursues a general SSE course over Snowy Plains with an average fall of 22 feet to the mile, turns abruptly SSW and eventually plunges into a wide gorge nearly 1,000 feet deep, where its gradient steepens so that it drops more than 600 feet to its junction with the Burrungubugge. The combined stream descends 250 feet in $\frac{3}{4}$-mile to meet the Snowy at 3,450 feet. From the point where the river enters the gorge Snowy Plains continue S for a mile to the low Kalkite Gap, through which the Gungarlin

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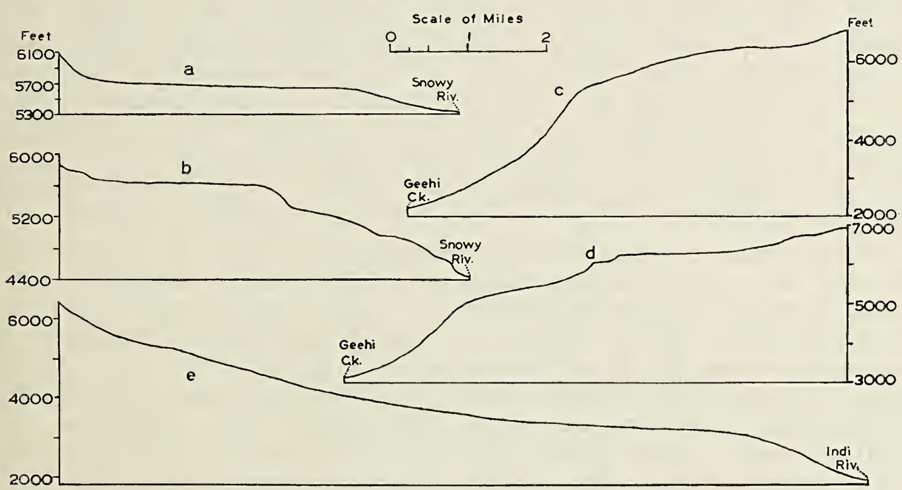
The largest of the Snowy tributaries is the Gungarlin which with its tributary the Burrungubugge drains an area of 90 square miles. Rising at 5,400 feet it pursues a general SSE course over Snowy Plains with an average fall of 22 feet to the mile, turns abruptly SSW and eventually plunges into a wide gorge nearly 1,000 feet deep, where its gradient steepens so that it drops more than 600 feet to its junction with the Burrungubugge. The combined stream descends 250 feet in ¾-mile to meet the Snowy at 3,450 feet. From the point where the river enters the gorge Snowy Plains continue S for a mile to the low Kalkite Gap, through which the Gungarlin may eventually be captured by Kalkite Creek. Farther upstream the river's low eastern bank is being attacked by other Eucumbene tributaries.

The Burrungubugge rises in a broad, swampy col at 5,300 feet and occupies a wide grassy valley to the point of entry of its only substantial tributary, Dead Horse Creek. Downstream its walls close in and it flows in a wide straight early-mature valley 800 to 1,000 feet deep, with a very even gradient of 75 feet to the mile. In the ½-mile before its junction with the Gungarlin it descends 650 feet.

The general aspect of the tributary pattern on the right bank of the Upper Snowy is very different. Spencers, Perisher and Pipers Creek systems, gathering in the drainage of the Ramshead Range, all include longitudinal components parallel to the Summit road lineament, pierce a granite barrier at or near the convergence of the tributaries, and flow directly to the Snowy.

The upper components of the Spencers Creek system mostly occupy wide, open, swampy valleys with walls averaging perhaps 400 feet high, all exhibiting marks of glaciation. These converge to a wide gorge 600 to



Text-fig. 5. Longitudinal profiles of (*a*) Spencers Creek, (*b*) Perisher Creek, (*c*) Wilkinson Creek, (*d*) Cootapatamba Creek, and (*e*) Leatherbarrel Creek. Note the inflexions in all of them, attributed primarily to rejuvenation consequent on differential uplift. The very gentle gradients of the upper parts of (*a*) and (*b*) are related to glacial erosion.

800 feet deep, its floor covered with boulders almost all the way to the Snowy. Along the left bank is a terrace from 100 to more than 200 feet above the creek bed, composed of or veneered with boulders large and small, including glacial erratics. At 5,600 feet A.S.L. its very gentle gradient begins to steepen and in its last mile it drops through 270 feet (Fig. 5). The valley-walls of Upper and Lower Spencers Creek show a distinct break of slope at 6,000 feet.

Lower Perisher Creek is formed by the convergence of several tributaries including two longitudinal ones. The trunk valley, nearly 4 miles long, is more open than that of Spencers Creek, with walls from 400 to 1,200 feet high. The gently-sloping tract down from the Summit road ends abruptly with a rapid 300-foot descent from 5,600 feet to a lower tract which slopes with increasing gradient to the Snowy at 4,400 feet. In this lower tract tributary valleys on the left bank hang high above the main stream (Fig. 5).

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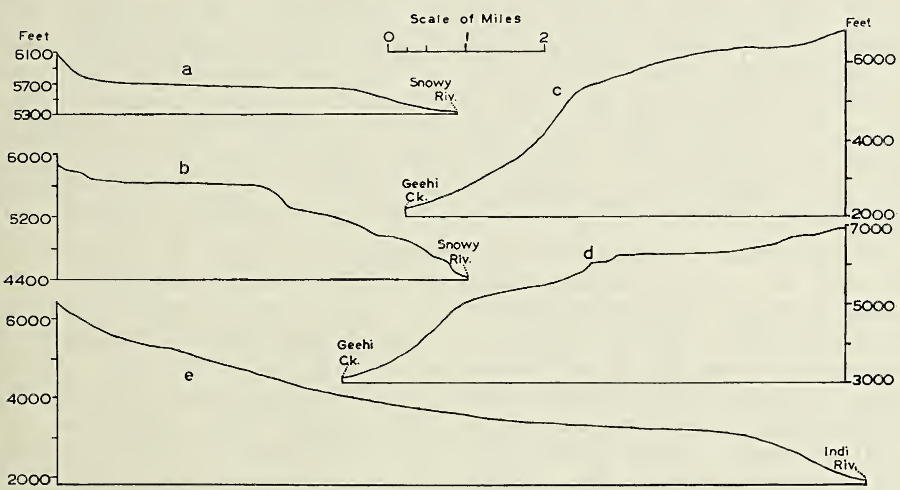

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The chief component of the Pipers Creek system is the longitudinal Upper Pipers Creek, which combines with the collinear Daners Creek to form Lower Pipers Creek. After breaching a low granite barrier and tumbling into a small basin this flows NW in a wide, straight, open valley contrasting with the gorges traversed by Spencers and Perisher creeks. The valley was evidently blocked by moraine at one point and the stream cut a diversion around the obstacle for nearly a mile. Traces of what look like old shorelines upstream may indicate temporary pondings of the creek. The head of rejuvenation is at 4,850 feet A.S.L. or 540 feet above the Snowy, and 1½ miles from it, and the flat floor of the glacial valley is cut into by a more rapidly deepening gorge. Farther down at ½-mile from the Snowy and 240 feet above it there is another steepening. The creek has a number of tributaries on both banks, some in bowl-shaped valleys probably hollowed by ice and hung as much as 100 feet above the floor of the trunk-valley.

These three creek-systems pose a problem. In each of them a series of tributaries or components with no great total volume of water (the Perisher components having the least) combine to form a single stream that makes its way to the Snowy through a barrier of granite, the first two helped by flowing in belts of shearing or intensified gneissosity. Quite possibly all the streams are antecedent and were able to keep cutting down against a slowly or intermittently rising fault-scarp. Pipers Creek appears to have had no aid from a shatter-zone, but may have carried a greater volume of water, and the barrier traversed by it was lower than elsewhere. The Pleistocene glaciers that occupied the valleys served to hasten erosion and perhaps to widen and deepen them. Griffith Taylor (1958, p. 228) briefly outlined a suggested explanation of these valleys that leans heavily on glacial action.

Farm Creek, collinear with Guthega River and cut in the same shear-belt, rises in a col in Perisher Range and follows a very straight course to the Snowy with a descent of 1,000 feet in almost 2 miles and a kink-point at 600 and another at 200 feet above the river. Diggers Creek flows north from Ramshead to join the Snowy below Island Bend at 3,750 feet. Its valley appears to have been glaciated down to at least 4,950 feet near the site of the old Hotel Kosciusko, where the creek begins to be entrenched in the glacial thalweg. A mile downstream a 50-foot waterfall possibly marks the head of a later rejuvenation, whence there is a drop of nearly 800 feet in 1½ miles to the Snowy. At ¼-mile from its mouth is a grassy flat, below which the creek tumbles down 100 feet into the river.

Crackenback.—The headwater stretch of this river makes a curious boathook bend, possibly related to a continuation of the fault along Jacobs River. In its long, straight course from Dead Horse Gap the river has cut a wide and deep gorge marking the course of the Crackenback fault. The disparity of surface altitude on either side is clearly apparent from Dead Horse Gap and Ramshead Range. It would seem that the present valley is incised 2,000 feet and more in a much older wide and shallow one, the traces of which are much lower on the Thredbo plateau than on the Ramshead Range. Incision of an inner valley to a depth of about 400 feet is well seen in the vicinity of Thredbo village, and successive rejuvenations within the main gorge are indicated by two inflexions in the thalweg, one at the exit from the Big Boggy marked by a descent of 600 feet in 3 miles, the other (200 feet in 1 mile) some 15 miles farther down. These inflexions may correspond with those in the Upper Snowy noted above.

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4 miles wide, with an area of 100 square miles. Nevertheless, with its remarkably straight course of 20 miles and its deep, wide valley the Crackenback is far more impressive than the Snowy; it is also rather more advanced in maturity, with a distinctly lower gradient—less than 85 feet to the mile below Dead Horse Gap—and a more alluviated floor. Apart from Little Thredbo River, which drops 1,700 feet in 8½ miles, the tributaries are short and steep, scoring the sides of the gorge, some of them on the left bank having gradients of about 900 feet to the mile. On the right bank gradients are not so steep and some tributaries have captured the waters of old shallow valleys on the Thredbo plateau; this may account for the inflexions shown by some of them. The Crackenback contrasts with the Wollindibby and Mowamba which, flowing at lower levels largely over medium-grained granite of Jindabyne type, are characterized by very gentle gradients and wide valleys over most of their courses. The peculiar course of China Creek, a tributary of Little Thredbo, is suggestive of structural control.

Indi.—The trend of this tortuous river though variable is in general NNW. For much of its length it is entrenched in a valley 2,000 feet and more in depth, but at Tom Grogin this opens out considerably, only to narrow again a few miles down to the Murray Gates defile. Some 15 miles up from its junction with Swampy Plain River it finally assumes an appearance of late maturity which persists beyond its junction with Tumbarumba Creek. South of Tom Grogin the steep banks of its gorge are deeply furrowed with consequent valleys and the rejuvenated parts of valleys that are mature on the plateau, such as those of Cascade Creek and Tin Mine Creek. At Tom Grogin Hut there are signs of two alluvial terraces, at about 20 and 60 feet above the river respectively. Near its head its course may have been determined in part by a fault (Crohn, 1950).

Swampy Plain River, formed by the confluence of Geehi River and Bogong Creek at 1,400 feet, is a considerable stream which, wide and alluviated at Geehi, plunges lower down into the impassable Devils Grip gorge, but a few miles farther downstream at Khancoban flows in a valley-plain over 3 miles wide which it has been suggested is a fault-trough. The Geehi River drains the most precipitous country of the whole region by consequent tributaries on its left bank which nearly all rise at or above 6,000 feet and are glaciated in their upper reaches. This river is formed by the confluence of Rocky Plain River and Back Flat Creek. The former, a late-mature or senile stream, rises at 6,500 feet on the southern slope of Jagungal and is joined at 4,850 feet by the Valentine, which tumbles over a 400-foot waterfall to meet it. Back Flat Creek, rising four miles south-west of Jagungal, takes a zigzag course with alternating gorge and flat, is joined by Straight Creek and meets Rocky Plain River in a valley 800 feet deep 200 yards above the mouth of Valentine River. The Grey Mare Range is deeply dissected by the Geehi tributaries on the east and those of Bogong Creek on the west and the Dargals Range is carved into a tangle of spurs and gorges by Bogong Creek on one side and Swampy Plain River on the other.

Both Geehi River and Bogong Creek show what appear to be vestiges of old outer valleys, and along the former Hall and Lloyd noted alluvial benches 50 feet above present river-level. Both have remarkably smooth and even gradients, averaging 160 and 190 feet to the mile respectively, due no doubt to the ease of erosion of the sedimentary belts in which their valleys are excavated, and perhaps to the presence of shatter-zones. By way of contrast Fig. 5 shows the thalwegs of three minor streams flowing down the western slope of the block. Two of these, Wilkinson and Leatherbarrel, appear to be consequent streams brought into being through the late-Pliocene

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The curious profile of Cootapatamba Creek betrays its immaturity. Like its affluent a little to the N it drains a cirquoid hollow cut in the riser of the 6,600-foot step and has had little success in sawing a way through fault-scarps and against gneissosity. The probable history of this creek has already been discussed (Browne *et al.*, 1955).

Tooma.—Much of the country W and NW of Jagungal is drained by Tooma River heading in a flat valley at 6,000 feet. Not far from its source it is diverted to the south by a meridional ridge and enters Bogong Swamp about a mile long, now partly drained and invaded by snowgrass; from this it emerges to the west by a gorge 400 feet deep, to flow for 4 miles obliquely across the Grey Mare step and join the mature, alluviated Pretty Plain Creek, the gorge deepening another 200 feet on the way. Four miles to the north of the swamp a smaller swamp is walled on the west by a continuation of the same scarp, here only 100 feet high. The topography suggests that the swamps on the east and the alluviated Pretty Plain valley on the west are related to the submeridional faults and shear-zones along the Geehi River and Bogong Creek respectively, or are contained in narrow local fault-troughs. From Pretty Plain the Tooma flows N for 15 miles, turns sharply W, crosses the Jagumba Range in a gorge more than 3,000 feet deep and traverses a lower block before emerging on to a wide valley at 900 feet A.S.L., where it is joined by Tumbarumba Creek.

Tumut.—This river rises a mile west of Jagungal on a flat at 5,400 feet and rapidly becomes entrenched in a little steep-sided, flat-floored grassy valley with a small hanging tributary on the right bank; farther down it is joined by Bogong Creek and Doubtful River, and according to Hall and Lloyd its course is influenced by two pronounced shear-zones. The gorge of the river deepens to more than 2,000 feet W of Kiandra and at Tumut Pond and elsewhere is seen to be deeply entrenched in an older valley. An important tributary from the SE is Happy Jacks River; this has carved out a broad, undulating valley-plain that narrows sharply downstream, in which it is entrenched ever more deeply as it nears the Tumut, which it meets at grade.

Glacial Sculpture

Many topographic features related to the Pleistocene glaciations have already been described (Browne and Vallance, 1957, 1963), and attention is here confined to a few of them. It is hoped to consider some aspects of the valley-glaciation more fully in a later paper.

In the glaciated country cirque-headed valleys are numerous. Typically they have curved heads and relatively steep walls at head and sides, giving rather abruptly on to a flat, swampy floor with gentle gradient containing some relics of moraine, and are most conspicuous and most deeply incised at the higher altitudes. Such a valley-form is most unlikely as a product of uplifts, and both have cut deep gorges into the steep slope. The former crosses the scarp of the Geehi Creek fault and the gneissosity of the granite at a high angle, and below the scarp is eroding a much less resistant metasedimentary belt; this combination accounts for the marked change in gradient at 5,200 feet. The course of Leatherbarrel Creek lies east of the Geehi Creek fault and for 4 miles it traverses a metasedimentary belt at an acute angle; upstream it crosses two other fault-scarps obliquely and parallel to the gneissosity with only one small kink, and its upper course is in a belt of metasediments in which it is vigorously eroding a steep-sided gorge. The convex curvature of the profile near its mouth matches the progressive entrenchment of the Indi into which it flows.

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Perhaps the best example is the Mawson cirque; another is the valley of Upper Spencers Creek heading in the multiple Charlotte cirque. South of The Paralyzer are the short circular-headed valleys of Amos Creek and the little unnamed creek east of it, both tributary to Betts Creek, and a mile to the east is the so-called Perisher cirque, really a small cirque-headed valley with a swampy floor 350 yards long. For all these the contour-pattern as shown on a large-scale map is essentially the same (see Browne and Vallance, 1963). Shallower examples are occupied by tributaries of Munyang River, Diggers Creek and Valentine River and probably also by tributaries of Tolbar Creek and the adjacent Burrungubugge River. Indeed the pattern is so constant and characteristic as to be tentatively diagnostic. In some instances the cirque-headed valley hangs above the floor of a trunk-valley, e.g., the Perisher cirque and some tributaries of Valentine River and Cascade Creek. The original steepness of the walls is apt to be lessened as the result of post-glacial weathering, and where river-erosion has been active the flat floors have been dissected and the valley-heads notched by tributary gullies. Cirque-heads modified in this way are to be seen around Mt. Anderson and elsewhere.

At the higher elevations hanging valleys are by no means rare, and in some instances erosion has pushed the hang a little way back from the mouth to form a kind of stepped valley. With normal river-erosion tributaries as a rule meet the parent stream at grade, but hanging valleys are familiar enough features in the Blue Mts. and other unglaciated parts of the State, the reason being inability of the tributary to keep pace with the deepening and/or widening of the parent owing to insufficient volume of water or the existence of a lithological, structural or other barrier. Some hanging valleys in the Kosciusko block are of this type and some are due to faulting, but there are others to which these explanations cannot logically apply, *viz.* those in which the valley has a catchment area equal to or greater than that above which it hangs. An outstanding example is afforded by Wrights Creek which, although it has a drainage-area more than twice the size of that of Upper Spencers Creek, empties into the latter with a sloping hang of more than 200 feet. In the same Spencers Creek system Guthrie Creek drops into the valley of an unnamed tributary of Betts Creek with a hang of more than 90 feet though their catchment-areas are approximately equal. Somewhat similar conditions obtain where the Perisher cirque drops more than 100 feet into the valley of Upper Perisher Creek, and where the main tributary of Upper Pipers Creek joins the parent stream between Pipers Gap and Smiggin Holes.

In the instances cited formation of the hang as a result of normal river-erosion is obviously out of the question, and one reasonable explanation seems to be that which postulates erosion of both valleys by ice, the normal volume of which in the lower valley may have been augmented by diffluence from adjacent glaciers. It is to be remembered also that when the possible volumes of glacier ice in two valleys are to be compared the cubic capacity of each valley, dependent in large measure on the height of its walls, must be taken into account no less than their respective catchment-areas.

In an earlier paper (Browne and Vallance, 1957, p. 129) it was noted that in a col at one of the heads of Rock Creek in the Ramshead Range there is a rather regular series of granite monoliths *in situ* of approximately river-erosion alone, and it is clear that, whatever its original character, it has been greatly modified by ice. Most of the valleys are short and might be regarded as rather elongated cirques, but precisely similar forms occur at the heads of quite long valleys (Fig. 5).

Perhaps the best example is the Mawson cirque; another is the valley of Upper Spencers Creek heading in the multiple Charlotte cirque. South of The Paralyzer are the short circular-headed valleys of Amos Creek and the little unnamed creek east of it, both tributary to Betts Creek, and a mile to the east is the so-called Perisher cirque, really a small cirque-headed valley with a swampy floor 350 yards long. For all these the contour-pattern as shown on a large-scale map is essentially the same (see Browne and Vallance, 1963). Shallower examples are occupied by tributaries of Munyang River, Diggers Creek and Valentine River and probably also by tributaries of Tolbar Creek and the adjacent Burrungubugge River. Indeed the pattern is so constant and characteristic as to be tentatively diagnostic. In some instances the cirque-headed valley hangs above the floor of a trunk-valley, e.g., the Perisher cirque and some tributaries of Valentine River and Cascade Creek. The original steepness of the walls is apt to be lessened as the result of post-glacial weathering, and where river-erosion has been active the flat floors have been dissected and the valley-heads notched by tributary gullies. Cirque-heads modified in this way are to be seen around Mt. Anderson and elsewhere.

At the higher elevations hanging valleys are by no means rare, and in some instances erosion has pushed the hang a little way back from the mouth to form a kind of stepped valley. With normal river-erosion tributaries as a rule meet the parent stream at grade, but hanging valleys are familiar enough features in the Blue Mts. and other unglaciated parts of the State, the reason being inability of the tributary to keep pace with the deepening and/or widening of the parent owing to insufficient volume of water or the existence of a lithological, structural or other barrier. Some hanging valleys in the Kosciusko block are of this type and some are due to faulting, but there are others to which these explanations cannot logically apply, *viz.* those in which the valley has a catchment area equal to or greater than that above which it hangs. An outstanding example is afforded by Wrights Creek which, although it has a drainage-area more than twice the size of that of Upper Spencers Creek, empties into the latter with a sloping hang of more than 200 feet. In the same Spencers Creek system Guthrie Creek drops into the valley of an unnamed tributary of Betts Creek with a hang of more than 90 feet though their catchment-areas are approximately equal. Somewhat similar conditions obtain where the Perisher cirque drops more than 100 feet into the valley of Upper Perisher Creek, and where the main tributary of Upper Pipers Creek joins the parent stream between Pipers Gap and Smiggin Holes.

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In an earlier paper (Browne and Vallance, 1957, p. 129) it was noted that in a col at one of the heads of Rock Creek in the Ramshead Range there is a rather regular series of granite monoliths *in situ* of approximately accordant heights of 10 feet above the general surface, and it was suggested that the interspaces were at the onset of glaciation largely occupied by decomposed rock which when frozen hard behaved like solid rock towards the passage of ice and eventually vanished through erosion in post-glacial time. A number of somewhat similar occurrences have since been noted, e.g., east of the col at the head of Betts Creek, on the right bank of Little Diggers Creek some 1,200 yards S of Alpine View, and on the right bank of Diggers Creek a little below where it is crossed by the Summit road. A particularly interesting example is that on the right bank of Betts Creek a little way downstream from the site of the now demolished Betts Camp; here the accordant tops of the granite monoliths instead of being on a plane are on a gently domed surface and give the impression of having formed part of a large *roche moutonnée* smoothed by the glacier that passed down the valley of Betts Creek.

Rocks and Rock-Structures

The major features of the landscape were, as shown above, determined by crustal movements, but geology has also played another role in shaping the topography that cannot well be ignored, both the rock-types and their structures, primary and superimposed, having been important. Valuable accounts of the rocks of much of the area are given in the reports by Hall (1955), Hall and Lloyd (1954), Adamson (1955) and den Tex (1959), and only the broader features are dealt with here.

The *terrain* includes igneous and metasedimentary rocks, the former being dominant. The most widespread is a coarse-grained grey granite or granodiorite, generally somewhat gneissic and believed to be of epi-Silurian age; it has a meridional extent of 70 miles. Small intrusions of epi-Ordovician granite are known chiefly from the vicinity of Geehi and Tumut Pond. Medium-grained massive granites, thought to be Devonian, occur typically around Jindabyne and for several miles N and SW of it, and there are coarser and more salic types around Khancoban and in the far south in the Tin Mine plateau, some of which are, perhaps, even younger.

The chief basic rocks are basaltic, forming dykes and other small intrusions, and in the northern extension there are also considerable remnants of Oligocene terrestrial flows overlying sedimentary deposits.

The metasedimentary rocks are chiefly in the western half of the block in belts from a few hundred yards to 5 miles across, with a general NNE trend, separated by granite. They consist of highly-folded Ordovician slates, phyllites, schists and quartzites. In the east an irregular outcrop, mostly quartzitic, appears just west of the Eucumbene River near Eastbourne bridge and extends thence north through Munyang Range.

These rocks possess varying resistances to weathering and erosion. The survival of the monadnocks around Mt. Kosciusko is related in large measure to the very salic character of the granite-gneiss composing them as well as to the direction of its marked gneissosity, though Mt. Townsend is of grey granite. The prominent ridge of the Etheridge Range, also composed of siliceous gneissic granite, contrasts with the more easily eroded granodiorite forming the basin that fronts it at the main head of the Snowy River. The medium-grained granite forming the Big Boggy at the head of Crackenback River, the Snowy valley at Jindabyne, the locally widened Snowy valley at Island Bend, and the wide Wollindibby and Mowamba valleys, is in general more easily eroded than the coarser, rather gneissic granodiorite it invades, and a similar characteristic helps to explain the wide depression drained by Little Thredbo River, and perhaps also the wide Swampy Plain valley south of Khancoban.

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The lowland corridor on the west of the Kosciusko block between Tom Grogin and Geehi may be a fault-trough, as suggested above, but the fact that it is excavated partly in somewhat biotitic epi-Ordovician granite which is fairly easily weathered, may have some significance. A coarse-grained massive granite also appears in this lowland and is accompanied on the east by a quartz-porphyry which, due to greater resistance, forms the higher foothills.

The belts of metasedimentary rock tend to erode easily except where composed of quartzite or where recrystallized to granulite or hornfels adjacent to granite intrusions. The collinear valleys of Upper Cootapatamba Creek and Upper Rawson Creek are in part excavated in soft phyllite, and the imminent recapture of the former by Leatherbarrel Creek (Browne *et al.*, 1955) is being facilitated by the fact that the latter is eroding its channel along the same narrow belt. The very straight course of Geehi Creek is contained within a belt of schist. Quartzitic rocks may form positive features like Nimmo Hill, Munyang Range and the country farther north, and the narrowing of the wide Happy Jacks valley downstream is due in part to its entering a belt of quartzite strengthened by igneous intrusions. Phyllite and old basaltic rocks recrystallized at a granite contact and laced with quartz veins compose the high ridge at the western end of Jagungal. In the SW the gorge of the Indi at Murray Gates and that of Swampy Plain River at Devils Grip Gorge are partly cut across a belt of resistant metasedimentary rocks that formed barriers resulting in the upstream widening of the valleys. Almost vertical slates form prominent features on Leatherbarrel Creek and near the falls on Tin Mine Creek, and in the far SW The Pilot ridge is of flinty quartzite.

Though the Kosciusko block contains several basaltic dykes, some of which are probably Tertiary, and basalt, as flow or intrusion, has been noted in the SW at 2,400 feet A.S.L. across the Indi from Tom Grogin Hut, only one small flow-remnant is definitely known, at 4,000–4,200 feet within the valley of Snowy Gap Rivulet, a tributary of the Eucumbene (Adamson, 1955). Most of the flows are in the northern extension, chiefly around Kiandra, and to the west of it in a belt running just east of Cabramurra township and south almost to Jagungal (Andrews, 1901; Hall and Lloyd, 1954). There are several flows, overlying deposits of Oligocene gravels, sands, clays, lignites, etc., and it is noteworthy that some are within the walls of existing valleys. In the valley of Tumut River up from its junction with Doubtful River the basalt is only 200 or 300 feet and in some places not more than 100 feet above the present valley-floor, and at Kiandra the base of the underlying sediments is some 400 feet below plateau level and perhaps 200 feet above the present Eucumbene. The Tumut and Eucumbene rivers thus date back to Oligocene time.

Farther down the Tumut the basalt, forming the Miocene peneplain, is as much as 2,500 feet above present river-level, giving some measure of the erosion since its uplift. The monadnocks of Tabletop and Round Hill are thought to mark centres of eruption (Andrews, 1901; Gill and Sharp, 1957). It is of interest that near Tooma on the down-faulted western side of the plateau the basalt is at 1,200 feet A.S.L., nearly 4,000 feet lower than at Kiandra.

The gneissic structure of the epi-Silurian granite is well developed in places but elsewhere virtually absent. The most common type is a primary foliation with a variable trend, generally NNW but changing to NNE, and with local curvature and a tendency near metasedimentary belts to strike parallel to the boundary. In certain zones the foliation has been accentuated, The lowland corridor on the west of the Kosciusko block between Tom Grogin and Geehi may be a fault-trough, as suggested above, but the fact that it is excavated partly in somewhat biotitic epi-Ordovician granite which is fairly easily weathered, may have some significance. A coarse-grained massive granite also appears in this lowland and is accompanied on the east by a quartz-porphyry which, due to greater resistance, forms the higher foothills.

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Both primary and secondary foliations have strongly influenced stream-directions, though not universally. For instance, Upper Snowy River where it turns SE below Island Bend seems to flow parallel to the foliation, but above the bend cuts directly across it. Lower Perisher Creek is in a belt of secondary foliation, but the summit of The Perisher is in the same belt and in the prominent Kangaroo ridge the granite is conspicuously sheared. Guthega River follows a rather narrow belt of shearing, which in its northward continuation meets the trend of a metasedimentary belt at an acute angle. The courses of some streams appear to have been determined by two or more shear-zones.

The primary foliation is presumably epi-Silurian; the belts of secondary foliation are younger but of the kind usually considered to result from the action of compressive or torsional stresses on solid rocks at great depth, and in some instances were evidently associated with upthrust, overthrust or transcurrent movement. The only field-evidence available suggests that they are pre-Oligocene, and they are almost certainly not younger than Palaeozoic.

The phyllites and other metasedimentary rocks are highly inclined as a rule, and where softer and more resistant types are interbedded stream courses have been influenced. Shearing and other forms of dislocation have been noted in several places, which may be related to the folding of the beds in late Ordovician time and/or to later orogenic movements. In some places, as at the head of the Tumut River (Hall and Lloyd, 1954), shearing has occurred along the boundary between metasedimentary and intrusive igneous rocks. Jointing and cleavage are very characteristic of the slates and quartzites, probably induced during folding. Under the influence of frost-weathering some of the quartzites, closely jointed in several directions, tend to form great surface accumulations of angular fragments.

Jointing is almost universal in the granite and very common in the metasediments. It may be vertical and horizontal, dividing the rock outcrops into cubical blocks, as at the main head of the Snowy, at the top of the chair-lift above Thredbo village, and at the falls on Munyang River and Diggers Creek; elsewhere there are concentrations of parallel vertical joints, such as are associated with normal faulting, as along Diggers Creek in various places, and on the Snowy at Long Corner below Island Bend. Close-spaced inclined jointing commonly accompanies shearing. Vertical jointing in two directions has induced a rude columnar structure on the southern side of The Blue Cow and the south-east face of Mt. Wheatley. Perhaps the commonest trend of vertical jointing is approximately NE–SW, but NS and EW directions are also important. Locally the granite has only wide-spaced apparently by post-consolidation pressure, with some crushing and recrystallization, as on the top of The Perisher, Back Perisher and Blue Cow, near the head of Wrights Creek, in the Snowy valley at Charlottes Pass, on the Alpine Way at The Pilot Lookout, and elsewhere. The strongly gneissic rocks tend to form rough, craggy outcrops and to weather into flattish ellipsoidal slabs. In some rather narrow belts more intense pressure has produced crush-zones or shear-zones. A vertical section across one of these is exposed in a road-cutting on the south side of the Crackenback bridge on the new Jindabyne–Kosciusko road; here the granite is rather intensely sheared over a width of perhaps 300 yards, the sheared rock dipping at about 70° in a direction *ca.* 330° (true). In a cutting on the north side of the bridge the granite is much jointed vertically in several directions, with some slickensides and a few thin sheared bands. Though no sign of an upstream continuation is evident on air-photographs the coincidence of trend leaves little doubt that the Crackenback fault and river are in the shear-zone.

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In certain places, e.g., the Snowy valley up from Jindabyne, the medium-grained massive granite is intersected by fairly close-spaced joints in three directions that seem to increase its natural tendency to weather.

Jointing has locally influenced stream-patterns, as along Diggers Creek between the old Kosciusko hotel and the Snowy and at the little hotel reservoir. Hall and Lloyd have noted the influence of well-developed joint-systems on stream-courses in the country drained by Valentine and Rocky Plain rivers, and air-photographs suggest stream control by two sets of vertical joints at right angles in the area between Lower Perisher and Lower Pipers creeks. Jointing has been an important factor in the formation of glacial cirques, as at Blue Lake and in the Clarke, Twynam and Etheridge Range cirques.

Of the age of this jointing nothing precise is known; some may be pre-Tertiary but probably most of it belongs to one or other of the Tertiary movements of uplift. Since the vanishing of the Pleistocene ice there has been, as the result of severe weathering, much manifestation of latent jointing.

Columnar jointing is common in the basalt flows, and in the deeply dissected country along the Tumut River has facilitated the formation of spectacular scree-slopes.

Evolution of the Topography

It is fairly well established that the entire highland belt of eastern New South Wales experienced significant movements of varying amplitude during three Kainozoic epochs. A Cretaceous peneplain was moderately elevated probably in the Eocene, during what may be called the *Kiandra Epoch* from the existence in the township and surrounding country of evidences of the uplift and its consequences. In the early Oligocene there was considerable dissection by rivers (cf. Voisey, 1942), with formation of deep valleys that became deeply alluviated, to be buried eventually beneath thick flows of basalt. A long interval of peneplanation and duricrusting was completed in Miocene time, the peneplain surface being cut indifferently out of Palaeozoic and Mesozoic strata, Palaeozoic granites and Oligocene basalts. The peneplain, much elevated and reduced largely to remnants, is now the most important and widespread surface in the State and perhaps indeed in the Commonwealth, and provides a useful reference datum for events in Kainozoic history. About the end of the Miocene, during what I have called the *Macleay Epoch,* elevation again took place, followed by a long Pliocene stillstand; during this some of the old drainage was dismembered, new rivers were formed and old ones were revived and brought to a condition of advanced maturity or even senility, giving rise to wide valleys and valley-plains like those of the Shoalhaven (Craft, 1931, 1932), Macleay (Voisey, 1957) and Murrumbidgee.* Later in the Pliocene episodic elevation on a grand scale occurred during the Kosciusko Epoch, and the cycle of river-erosion then established still continues.

* Part of the Yass–Canberra Tableland of Sussmilch (1909).

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* Part of the Yass–Canberra Tableland of Sussmilch (1909).

The chronological scheme outlined above, based on the pioneer work of Andrews (1910), is believed on the whole to fit the known facts most satisfactorily. According to the generally accepted view, which the present study tends to confirm, differential elevation of the Kosciusko block above the surrounding country was an episode in the epeirogenesis of the Kosciusko epoch, though Craft (1933, p. 238) seems to regard the block as a kind of gigantic monadnock which may have existed since late Palaeozoic time and has survived many cycles of peneplanation.

In the Kosciusko block and its extensions no definite signs of the Cretaceous peneplain are known, but the residuals scattered over the surface may be relics or reduced remnants of it. Following the Kiandra uplift, with which, as with the later Macleay uplift, some faulting was doubtless associated, valleys more than 1,200 feet deep (Gill and Sharp, 1957) were cut in it and became wide and mature, with heavily alluviated floors. Possibly, as Andrews suggested for other parts of the State, some down-faulting or warping caused the valleys to be choked with fine alluvium before the outpouring of the Oligocene basalts began. Repeated lava outbursts, punctuated by quiescent intervals of alluviation and soil-formation, filled the valleys and built up a thickness of several hundred feet of basalt. The difference in altitude between the supposed volcanic plugs, Tabletop Mt. and Round Mt., and the present basalt surface gives a minimum value for original aggregate thickness of the flows, which may have been at least 800 feet. The Miocene peneplanation reduced the surface level considerably, wiping out all or most of the basalt in the Kosciusko block and leaving in the northern extension little beside remnants of valley-fillings. This peneplain is believed to form the extensive surfaces visible at different altitudes in the area, and some of the shallow, alluviated gutters on the surface may be relics of the Miocene drainage. However, wide valleys and valley-plains were excavated during the long earlier Pliocene stillstand following the Macleay uplift, and many of them were rejuvenated during the differential elevations of the Kosciusko Epoch. These must have been virtually completed before the Kosciusko glaciation (which affected only the highest parts of the uplifted block), and are therefore reasonably ascribed to late Pliocene and/or early Pleistocene time. Evidence of at least three stages of movement may be recognized in the Snowy and Crackenback valleys, and the small earth-tremors that are not uncommon in the region (Cleary *et al.*, 1964) show that minor adjustment of fault-blocks is still going on.

Nature of the Uplift

The topography and the profile-sections across the area make it reasonably clear that there has been differential uplift and block-faulting, but the mechanism of movement is obscure. There may have been successive upfaultings of parallel crustal strips, with the highest reaching its present position last of all, or perhaps a kind of domal uplift with compensational adjustments leading to downfaulting in steps; the present superior elevation of the block would then be the algebraic sum of the movements, positive and negative, since the beginning of the Kosciusko epoch.

Block-faulting, trough-faulting and tilting of fault-steps are generally assumed to result from repeated normal or gravity faulting, and the appearance of the *terrain* is consistent with this explanation. On the other hand it has been shown that a curved or cylindrical fault, though definitely upthrust, may at the surface produce a scarp like that of normal fault: from the repetition of such faults the appearance of normal step-faulting might arise, but it is hard to see how this mechanism alone could produce a horst-like mass with the fault-pattern of the Kosciusko block.

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den Tex (1959) found olivine-basalt dykes (?Tertiary) displaced by revived normal faults and alluvial sediments along Geehi and Swampy Plain rivers apparently affected by normal faulting.

Cleary *et al.* (1964) have reported that the epicentral points and depths calculated for recent earth-tremors just outside the Kosciusko area suggest overthrusting from the north-west, but it is known that minor adjustments on normal faults may result in small reversals of movement, such as are seen, for example, in the monoclinal flexure and faulting where the Blue Mts. plateau gives on to the lowland Cumberland Basin. To sum up, the topographical evidence is quite consistent with, and even suggestive of, normal faulting but does not actually prove it.

Whatever the mechanism involved in the uplift of the Kosciusko block, it seems clear that the crustal strains generated were largely relieved by differential movements upward and/or downward on fault-planes situated in pre-existing zones of weakness of appropriate azimuth. This appears to be the only way of accounting for the paradox that post-Miocene fault-blocks are bounded by zones of pre-Tertiary foliation and shearing.

Evolution of the Drainage

The region must have had its quota of rivers long before the dawn of Tertiary time, but the earliest drainage of which recognizable traces survive is that of the early Oligocene, represented now in the dissected basalt-capped alluvial leads at Kiandra, Cabramurra and elsewhere, and in the valleys of Fryingpan, Buckenderra and a few other creeks. These formed part of north-flowing systems that took their rise on an arcuate watershed 20 miles SSW and 30 miles SE of Kiandra. It is very probable that within the Kosciusko block proper there were Oligocene ancestors of the present stream-systems and that these survived into the Miocene, when they meandered across the peneplain in senile fashion, themselves and their tributaries largely adjusted to rock-structures. During the late Miocene Macleay epoch of uplift they were revived, and in the Pliocene stillstand their valleys attained a state of very advanced maturity. To this time we may assign the outer valleys of the Eucumbene, Snowy, Crackenback, Indi and Tumut and many of their tributaries, Happy Jacks Plain and Snowy Plains, also the shallow valleys and valley-remnants on the plateau S of Jagungal, in the Ramshead Range and on the Thredbo plateau. It may have been during this epoch of revived activity that the Eucumbene captured by headward extension a number of north-flowing tributaries of the Murrumbidgee at Kiandra and south of it, relics of the Oligocene drainage. In respect of the movements of the Kosciusko epoch many of these Pliocene rivers and creeks are antecedent, as their engorged stretches testify, but towards the original zones of dislocation they are, of course, subsequent.

With the differential Kosciusko movements came rejuvenation and entrenchment of the rivers and the initiation and development of the inner gorges of the Upper Snowy, Crackenback, Indi and other rivers and of the steep consequent tributaries of some of the main streams, with the establishment of the present cycle of erosion. Among the last streams to be brought into being were some of those draining cirques, e.g., Club Lake Creek and Blue Lake Creek, which seem to belong to the interval between the valley- and cirque-glaciations. The diversion of Upper Cootapatamba Creek to Lower Cootapatamba valley must have taken place at this time or at the very end of the Pleistocene.

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Conclusion

The casual study of a topographical map or a scale-model of the Kosciusko area leaves one with the impression that the boundaries of the fault-steps, the courses of the main streams and many of their larger tributaries, and the topographic pattern generally, have been determined entirely by the late-Tertiary faulting. If, however, the interpretation given in these notes is correct it would seem rather that the tectonic pattern was in its essentials worked out far back in geological time during one or more Palaeozoic orogenies. Most of the Kainozoic movements may thus belong to the category of resurgent tectonics (Hills, 1963) and the epeirogen may really be part of a rejuvenated orogen. To reverse a venerable dictum, the past is here the key to the present, and the existing topography exemplifies the principle of what may be called *physiographic predestination,* a principle that doubtless holds elsewhere in the Palaeozoic *terrain* of the eastern highlands.

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EXPLANATION OF PLATE

Map of the Kosciusko Block and its northern and southern extensions showing lineaments and postulated Kainozoic faults.

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